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Using the simulation modeling with stochastic estimation of trafficability of forest transport systems

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Abstract. Forecasting trafficability of logging and forest transport systems on the ground, which have a multi-sectional layout solution is considered in the paper. Trafficability problems are evaluated from the point of view of the stochastic character of indicators of traction properties - the forces of resistance to movement and the adhesion force of the driving wheels with the supporting surface. With the stochastic estimation of trafficability the law of Gaussian distribution for random values of the rolling resistance coefficient and the two-parameter Weibull distribution law with a negative asymmetry coefficient or values of the shape parameter greater than 4 for the cohesion coefficient was adopted. A stochastic approach to the evaluation of trafficability allows to ensure a rational distribution of the power flows between propulsors of the transport-technological system, which is shown in this paper.

1. Introduction

The work of transport-technological machines in some sectors of the economy is very specific. This is due to their use on temporary roads or off-road conditions. In the forest industry, for example, the operation of transport systems occurs mainly on simplified temporary roads, which constitute about 40% of all types of forest roads. The emergence of new, more energy-saturated multi-operational machines makes it possible to mechanize most of the work in the sectors of forestry, agriculture, oil and gas and mining complexes, the defense industry, and other areas of the national economy. The use of all-wheel drive transport systems based on activation of the trailer structure and use of the articulated transport and technological machines is one of the promising directions in solution of many problems arising in transport and technological complexes operation in conditions of winter roads, dirt roads during dissolution and in other specific conditions. When creating such machines, the problem arises of predicting their off-road performance and, as a consequence, the distribution of power flows between the driving wheels in the process of motion.

2. Theoretical part

As a criterion for estimating the supporting traction capability of a vehicle under specific road conditions, the following inequality is used:



$$P_{\psi} \leq P_{\kappa} \leq P_{\varphi} \quad (1)$$

where P_{ψ} – total resistance to movement of ASTS; P_{φ} – total traction of the wheels of the ASTS with a supporting surface; P_{κ} – sum of the elementary tangential reactions in the contact zone of the driving wheels with the supporting surface.

Non-compliance (1) leads to the loss of the cross-country ability due to low coupling capabilities of the propulsion unit with a supporting surface, or because of a lack of traction capabilities of the vehicle. The preliminary traction calculation implies that if the tractive force value lies in the interval limited, on the one hand, by the maximum force of resistance to movement, and on the other hand by the force of adhesion of the engine to the supporting surface, then in the road conditions the vehicle permeability is provided. These considerations are taken as the basis for the deterministic approach to the choice of the magnitude of the torque applied to the motor P, which was described by the author in [1]

This approach does not take into account the stochastic nature of the change in coefficients ψ and φ .

It is shown in [2,3,4,5,6,] that the coefficient of total resistance to movement and the coefficient of cohesion of the propulsion device with the soil are not stochastic but determinate. Based on the processing of the statistical material, the laws of random values distribution of the total resistance and adhesion coefficients are obtained:

- ψ obeys the normal distribution law;
- φ obeys the two-parameter Weibull distribution law with a negative asymmetry coefficient and a form parameter greater than four or a truncated normal distribution. Thus, the situation is possible when, due to dispersion in the random values of the adhesion and drag coefficients, the value of the propulsion thrust will be outside the range determined by the inequality (1).

The distribution density function for the coefficient ψ [2,3,9,10] is as follows :

$$f(\psi) = \frac{1}{\sigma_{\psi} \sqrt{2\pi}} \cdot \exp -\frac{(\psi - m_{\psi})^2}{2\sigma_{\psi}^2} \quad (2)$$

where ψ – random (probable) value of the drag coefficient; m_{ψ} – mathematical expectation of ψ ; σ_{ψ} – is a standard deviation of the coefficient ψ .

$$m_{\psi} = \sum_{i=1}^n m_{\psi i} \cdot p_i \quad (3)$$

$$\sigma_{\psi}^2 = D_{\psi} = \sum_{i=1}^n (m_{\psi} - m_{\psi i})^2 \cdot p_i \quad (4)$$

where $m_{\psi i}$ – mathematical expectation of magnitude ψ for i -x road conditions; p_i – probability i -x road conditions.

These values are obtained by processing significant arrays of experimental information. For a particular i -th type of road conditions (with continuous recording of rolling resistance) the following is determined:

$$m_{\psi i} = \frac{1}{L} \int_0^L \psi(x) dx \quad (5)$$

where L – length of record ψ ; x – current value of the length of the site.

In discrete recording the value of the coefficient of total resistance to movement ψ is written:

$$m_{\psi i} = \frac{1}{k} \sum_{j=1}^k \psi_{ij} \quad (6)$$

where ψ_{ij} – j -e magnitude ψ_i , measured at one of the typical k sites.

3. Experimental part

To assess reliability of ATS during the test, the following mileage values are usually adopted in different road conditions (for all-wheel drive vehicles in %) [4,5]:

- improved roads - 20;
- cobblestone, gravel, crushed stone - 30;
- ground in satisfactory condition - 30;
- broken ground - 10;
- ground in the mud, off-road - 10.

Accordingly, [2,9,10]:

$$P_1 = 0,2; P_2 = 0,3; P_3 = 0,3; P_4 = 0,1; P_5 = 0,1.$$

Instead of the distribution function $f(\psi)$ the probability distribution function $p(\psi)$, is used in practice which determines the probable occurrence of a certain resistance on the road segment.

For any range of values ψ_1 and ψ_2 are written as:

$$p\{\psi_1 < \psi < \psi_2\} = \int_{\psi_1}^{\psi_2} f(\psi) d\psi = \frac{1}{\sigma_\psi \sqrt{2\pi}} \cdot \int_{\psi_1}^{\psi_2} \exp \left(-\frac{(\psi - m_\psi)^2}{2\sigma_\psi^2} \right) d\psi \quad (7)$$

The form of this function is exactly the same as for $f(\psi)$, but it is given in fractions (or percentages) of the current value of the coefficient ψ from the total probability of all values of ψ , which is equal to one (or 100%). From the graph of this function, the distribution parameters and the relative different values of the coefficient ψ are determined.

The three sigma rule is fulfilled:

$$\begin{aligned} m_\psi &= \pm \sigma_\psi \rightarrow 68,26 \% \\ m_\psi &= \pm 2\sigma_\psi \rightarrow 95,45 \% \\ m_\psi &= \pm 3\sigma_\psi \rightarrow 99,73 \%. \end{aligned}$$

The values of the mathematical expectation and the standard deviation of the coefficient of total resistance to movement for various road conditions are given in Table 1.

Changes in the coefficient φ are broader than ψ (figure 1), and do not obey a normal distribution (since there is an effect of climatic factors and precipitation). Coefficient φ , as mentioned earlier, obeys the two-parametric Weibull distribution with a negative asymmetry coefficient or values of the form parameter greater than 4:

$$f(\varphi) = \frac{m}{t_0} \cdot t^{m-1} \cdot \exp \left(-\frac{t^m}{t_0^m} \right) \quad (8)$$

where $m > 0$ – is the form parameter; $t_0 > 0$ – is the scale parameter.

The condition of motion can be written differently:

$$\psi < D < \varphi \quad (9)$$

Table 1. Characteristics of the distribution density. The coefficient of total resistance to movement

Road conditions	m_ψ	σ_ψ
With a hard coating	0.022	0.012
Cobblestone, gravel, crushed stone	0.032	0.018
Ground in satisfactory condition	0.045	0.022
Broken ground	0.08	0.030
Off-road	0.16	0.045

Thus, due to dispersion in the random variables ψ and φ , the value of D (or P_u) will be within the range determined by this inequality.

The distribution density of the random values of the coefficients of adhesion and the total resistance to motion is shown in Fig 2. The adb area characterizes the probable of loss of trafficability if

random values of the coefficient ψ fall into the interval cb , and the coefficient φ - in the interval ac . In this case, deterministic calculation gives a 100% fulfillment of the inequality (1), but in fact there is a loss of trafficability in the cohesion or resistance ($\approx 20\%$ of cases).

The approach to estimating a probable of loss of the off-road performance is used to determine the amount of torque that must be realized on the wheels of the first and second sections, and allows maximum use of traction and coupling capabilities of the articulated vehicle.

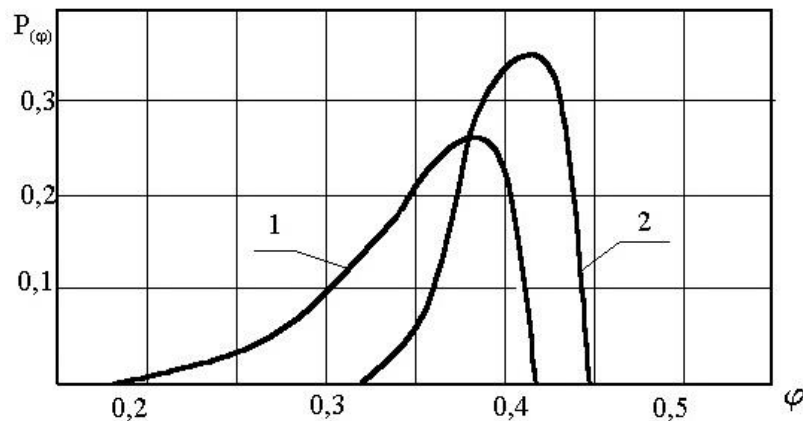


Figure 1. Density distribution of values of the coefficient of adhesion for various soil conditions: 1 - dirt road satisfactory condition; 2 - dirt road to mudslide

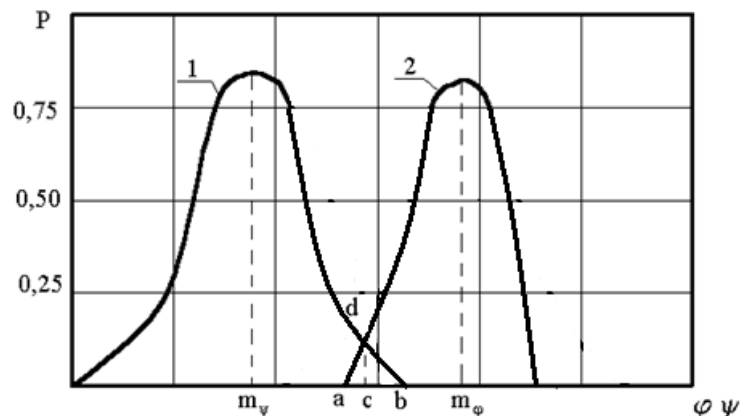


Figure 2. Density distribution of values of the coefficients of total resistance to movement (1) and adhesion (2)

To implement the methodology, a KALA program was created in Python. The algorithm of the program allows in a given range to realize random values of the coefficients of adhesion and resistance, distributed according to the corresponding law. The root-mean-square deviation is taken from the results of the experimental data. Based on the obtained values of the coefficients, traction forces for traction and resistance of movement for a particular machine are calculated. With the obtained values of traction forces, the actual value of the total longitudinal force for the given vehicle is compared. Two counters are used to summarize cases of non-observance of the right and left parts of inequality (1).

As a longitudinal thrust force on the propulsor of the second section of the ASTC, the part of the maximum possible thrust force realized at each transmission in the gearbox, taking into account the losses in transmission, is assumed.

The number of implementations in the calculation is set in interactive mode.

Further, the probability is calculated for the case when the realized longitudinal forces on the propulsion device are greater than the cohesion force or less than the total resistance force.

For example, with 1,000 implementations (i.e., 1000 times the values of the coefficients of adhesion and total resistance to movement are generated), the probable loss of cross-country ability in the first gear for a KrAZ-260 truck on an icy road with a selection of 25% of the total engine torque per active trailer will be 19,5 %. Deterministic calculation under the same initial conditions shows the inequality observance (2.18), that is, motion must be ensured. The running time of the program with 1,000 implementations is 4.5 seconds.

4. Results of the experiment and their analysis

Graphical dependence of a probable loss of the cross-country ability of the second section of the ASTS is shown in Fig 3-5 on the magnitude of the longitudinal force on the propulsor of the second section, as a percentage of the longitudinal force on the propulsor of the first section.

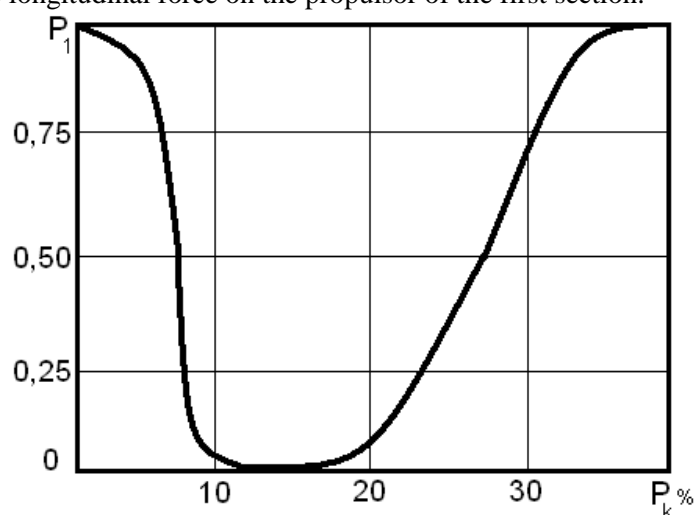


Figure 3. Dependence of a probable loss of trafficability on the longitudinal force on the engine of the second section of the ASTS (with isolated motion). Road - icy: $\varphi = 0,05 - 0,15$; $\psi = 0,025 - 0,05$

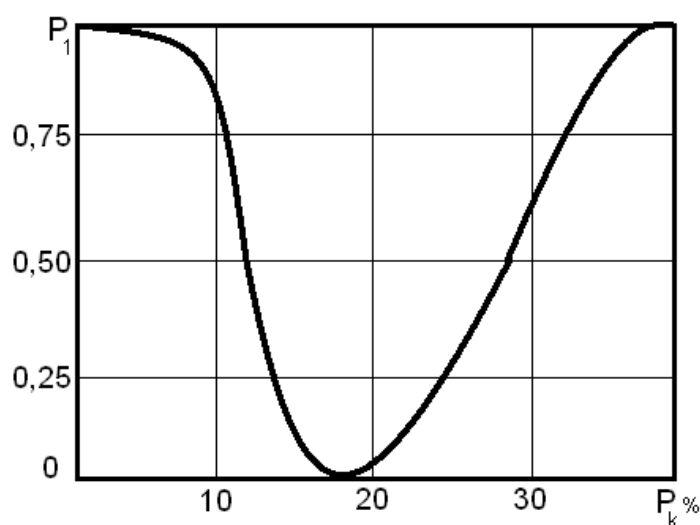


Figure 4. Dependence of a probable loss of trafficability on the longitudinal thrust on the engine of the second section (in the absence of longitudinal force on the propulsor of the first section). Road - icy: $\varphi = 0,05 - 0,15$; $\psi = 0,025 - 0,05$

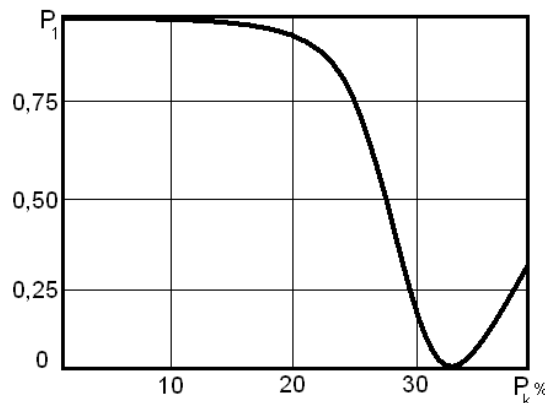


Figure 5. Dependence of a probable loss of trafficability on the longitudinal force on the wheels of the second section (in the absence of longitudinal force on the propulsor of the first section). Road - dirt road in the mud: $\varphi = 0,25 - 0,35$; $\psi = 0,15 - 0,25$

On the graphs, extreme sections corresponding to the minimum probable loss of trafficability are evident. The left branch of the curves corresponds to the loss of trafficability in the resistance (failure of the right side of inequality (1), that is, the longitudinal force is less than the total resistance to movement.) The right branch is the loss of trafficability on the linkage (the right-hand side of inequality (1)).

5. Conclusion

Thus, when creating the ASTS, it is necessary to take into account the most specific conditions the transport system is planned to be used, and to introduce the ratio resulting from the simulation into the drive of the second section engine [7,8]. If the ASTS is designed for operation under various road conditions, the design of the drive must include devices that monitor the condition of the pavement and automatically introduce adjustment of the value to be measured on the propulsion unit of the second torque section.

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